Experimental Verification of Double Negative Property of LHM with Significant Improvement in Microstrip Transceiver Parameters in S Band

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Abstract

In this work, a rectangular microstrip transceiver has been designed integrated with rectangular SRR based metamaterial structure at a height of 3.276 mm from the ground plane. Metamaterial has the ability to improve the parameters of antenna due to its focusing effect from its negative refractive index characteristics. Here design of rectangular split ring resonator based metamaterial structure is proposed, which has been superimposed on RMT at a height of 3.276 mm from its ground plane. This work is mainly focused on increasing the potential parameters of rectangular microstrip transceiver. The microstrip transceiver along with the proposed metamaterial structure is designed to resonate at 2.301 GHz. Simulation software is used to compare the bandwidth, return loss, directivity and efficiency of the rectangular microstrip transceiver at a frequency of 2.301 GHz with the proposed metamaterial structure. Simulation results showed that the impedance bandwidth of the RMT is improved by 487%, return loss is reduced by 117%, directivity is improved by 96% and efficiency is improved by 22% through the incorporation of the proposed metamaterial structure. In this work the values of permeability and permittivity of proposed innovative metamaterial structure are obtained by using a fictitious rectangular waveguide having perfect electric conductor and perfect magnetic conductor walls. For verifying that the proposed metamaterial structure possesses negative values of permeability and permittivity within the operating frequency range, Nicolson-Ross-Weir method (NRW) has been employed. For all simulation purpose, computer simulation technology-microwave studio (CST-MWS) Software has been used.

Keywords

Left Handed Metamaterial (LHM); Rectangular Microstrip transceiver (RMT); Impedance bandwidth; Return loss; Nicolson-Ross-Weir (NRW); Split Ring Resonator (SRR).

Introduction

Rectangular microstrip transceivers are designed on a dielectric substrate, which is composed of a radiating transceiver on one side and ground plane on the other side, both of which are characterized with low profile, lightweight, low cost. Besides of a lot of advantages, these transceivers have some drawbacks like narrow-bandwidth, low gains, high return loss etc. To overcome the above drawbacks, Victor Veselago introduced the theoretical concept of metamaterials. According to the theory of Veselago, these are generally artificial materials used to provide properties, being absent in materials of nature. To improve the performance of rectangular microstrip transceiver, J.B. Pendry and his colleagues added more information, who proved that the array of metallic wires can be used to obtain negative permittivity and split ring resonators for negative permeability. On the basis of this information, D. R. Smith and his colleagues fabricated a structure in 2001, which was a composition of split ring resonator and thin wire. It had been observed that the structure proposed by them possessed the negative values of permittivity and permeability simultaneously and was named as LHM.

The transceiver generally made of conducting material such as copper or gold, can be taken as any possible shape. The radiating transceivers and the feed lines are usually photo etched on the dielectric substrate. In order to simplify analysis and performance prediction, the transceiver is rectangular. For rectangular transceivers, the length L of the transceiver is usually $0.3333\lambda o < L < 0.5\lambda o$, where λo is the free-space wavelength. The transceiver is selected to be very thin

such that $t << \lambda o$ (where t is the transceiver thickness). The height h of the dielectric substrate is usually $0.003\lambda o \leq h \leq 0.05\lambda o$. The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \leq \varepsilon_r \leq 12$.

In this work "rectangular split ring resonator" as a metamaterial structure has been introduced to reduce the return loss and ameliorate the bandwidth, directivity and efficiency of the RMT. Variations in metamaterial substrate have not been done due to the affect of metamaterial substrate size variation on the transceiver parameters. Along with these outcomes, it has been observed that this structure satisfies the double negative property within the operating frequency range.

Design Methodology

The RMT parameters are calculated from the formulae given below.

A. Desired Parametric Analysis.

Calculation of Width (W)

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

$$L = Leff - 2\Delta L \quad (2)$$

Where,

$$Leff = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad (3)$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{W}}}\right) \quad (5)$$

In the above used formulas, the symbols have their usual meanings.

The parameter specifications of rectangular microstrip transceiver are mentioned in Table-1.

TABLE 1RECTANGULAR MICROSTRIP TRANSCEIVER SPECIFICATIONS

Parameters	Dimensions	Unit
Dielectric Constant (εr)	4.3	-
Loss Tangent (tan∂)	0.02	-
Thickness (h)	1.6	mm
Operating Frequency	2.301	GHz
Length (L)	29.7794	mm
Width (W)	38.3934	mm
Cut Width	5	mm
Cut Depth	10	mm
Path Length	20	mm
Width Of Feed	3.8	mm

Dimensional view of Rectangular microstrip transceiver at a resonating frequency of 2.301 GHz is given in Figure 1.

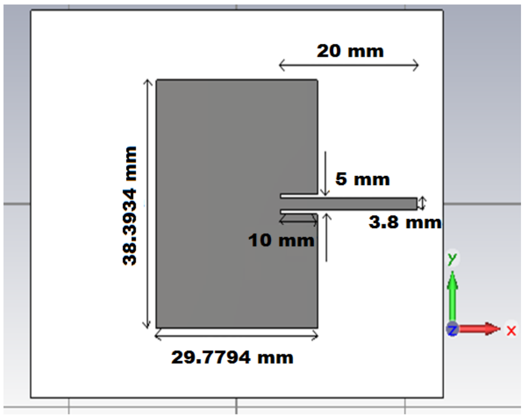

FIG. 1 RECTANGULAR MICROSTRIP TRANSCEIVER AT 2.301 GHz.

After the RMT simulation, the metamaterial cover is implemented over the transceiver at the height of 3.276 mm from the ground. The proposed metamaterial structure implemented as the cover of transceiver with its dimension used in the proposed design is shown in figure 2.

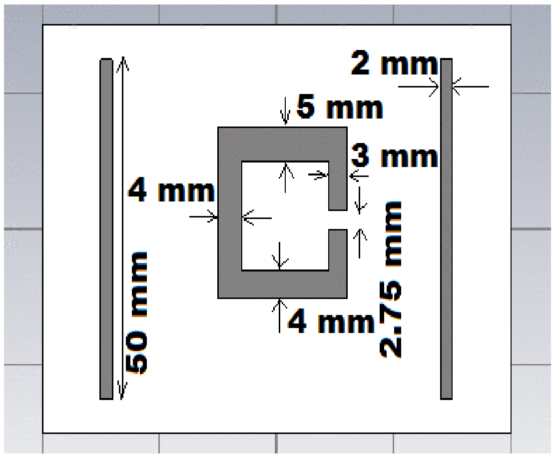

FIG. 2 PROPOSED METAMATERIAL STRUCTURE AT THE HEIGHT OF 3.276 MM FROM GROUND.

Rectangular Microstrip transceiver with proposed metamaterial is given below in Figure 3.

Return loss S_{11} and Impedance Bandwidth of Rectangular Microstrip transceiver shown in Figure 4 are -10.26 dB & 16.2 MHz respectively. Return loss S_{11} and Impedance Bandwidth of Rectangular microstrip transceiver with proposed metamaterial structure shown in Figure 5 are -22.28 dB & 95.1 MHz respectively.

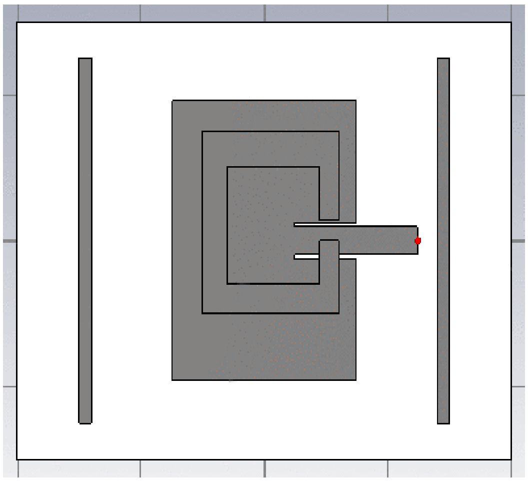

FIG. 3 RECTANGULAR MICROSTRIP TRANSCEIVER WITH PROPOSED INNOVATIVE METAMATERIAL STRUCTURE.

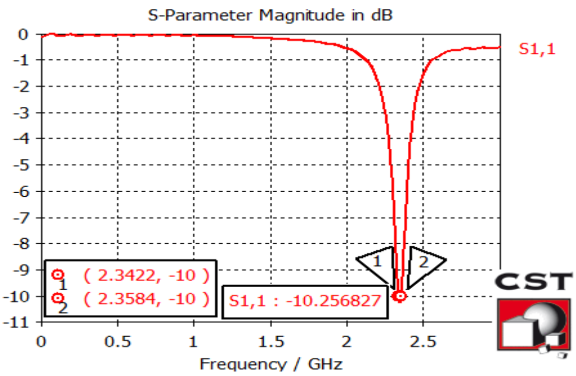

FIG. 4 SIMULATION OF RETURN LOSS S_{11} AND IMPEDANCE BANDWIDTH OF RECTANGULAR MICROSTRIP TRANSCEIVER.

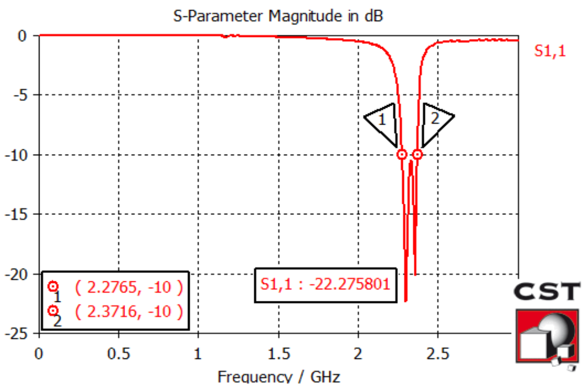

FIG. 5 SIMULATION OF RETURN LOSS S_{11} AND IMPEDANCE BANDWIDTH OF RMT WITH PROPOSED METAMATERIAL STRUCTURE.

From Figure 4 & 5, it has been observed that the return loss has significantly reduced by 117% and bandwidth has increased by 487% by via the incorporation of proposed metamterial structure with RMPA.

According to figure 6 showing three dimensional radiation pattern of rectangular microstrip transceiver, directivity and efficiency are 3.570 dBi &-3.453 dB respectively.

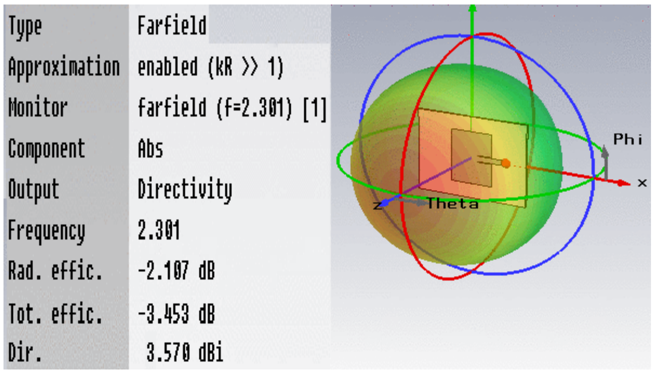

FIG. 6 RADIATION PATTERN OF A RECTANGULAR MICROSTRIP TRANSCEIVER.

While that transceiver with proposed metamaterial structure in figure 7, the directivity and efficiency are 6.484 dBi & -3.453 dB respectively.

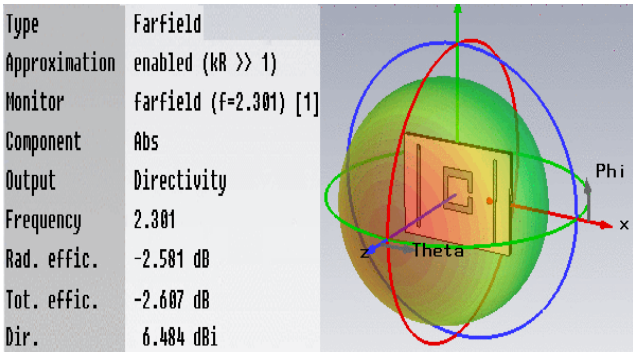

FIG. 7 RADIATION PATTERN OF A RECTANGULAR MICROSTRIP TRANSCEIVER WITH PROPOSED METAMATERIAL STRUCTURE.

Smith charts play a significant role in a transceiver as it provides valuable information about impedances at different frequency point so that decision on the impedance matching can be made. From Figure 8 & 9, it is clear that the RMT with the proposed metamaterial structure provides better impedance matching at 2.301 GHz, when compared to RMT alone. In Figure 9 & 10 E-Field & H- Field of RMT with proposed metamaterial structure are shown.

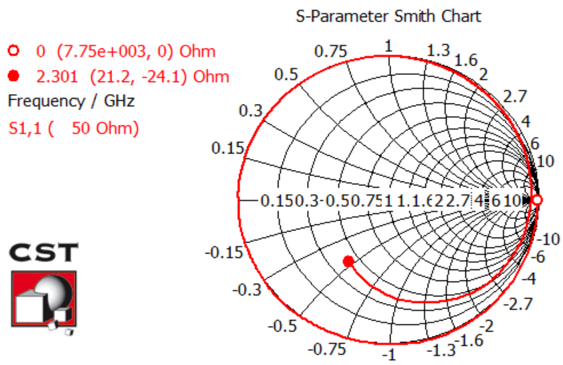

FIG. 7 SMITH CHART OF RECTANGULAR MICROSTRIP TRANSCEIVER.

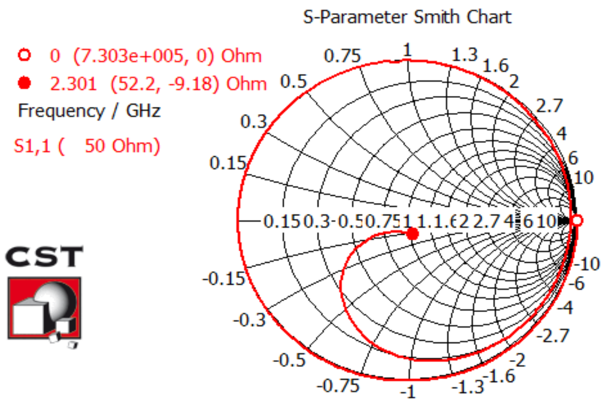

FIG. 8 SMITH CHART OF RMT WITH PROPOSED METAMATERIAL STRUCTURE.

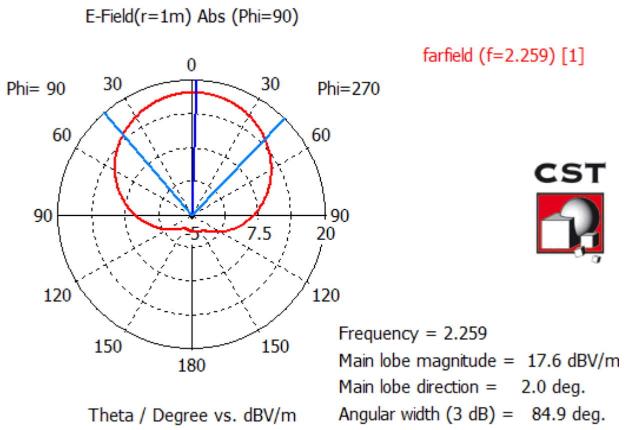

FIG. 9 E-FIELD OF RMT WITH PROPOSED METAMATERIAL STRUCTURE.

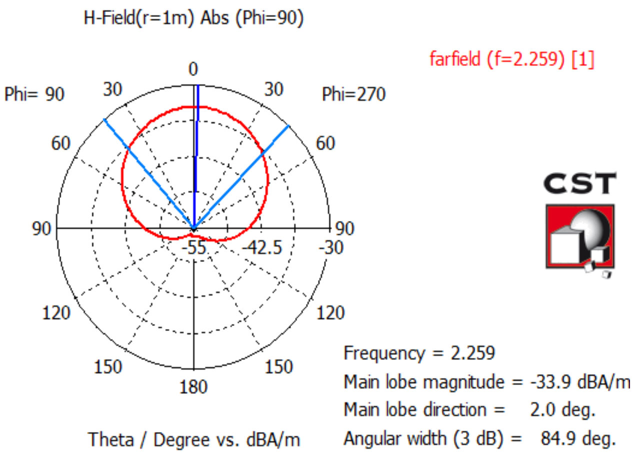

FIG. 10 H-FIELD OF RMT WITH PROPOSED METAMATERIAL STRUCTURE.

Nicolson-Ross-Weir (NRW) Approach

After the comparison, it is necessary to prove that the material here used to enhance the parameters of RMT is Meta which is validated by NRW (Nicolson Ross Weir) approach. The following formulas belong to NRW approach.

$$\mu_r = \frac{2.c(1-v2)}{\omega.d.i(1+v2)} \quad \ldots. \quad (6)$$

$$\varepsilon_r = \mu_r + \frac{2.S11.c.i}{\omega.d} \quad \ldots \quad .(7)$$

Where,

V_2 = S21 - S11

ω = Frequency in Radian,

d = Thickness of the Substrate,

c = Speed of Light,

V_2 = Voltage Minima.

μ_r = Relative permeability

ε_r = Relative permittivity

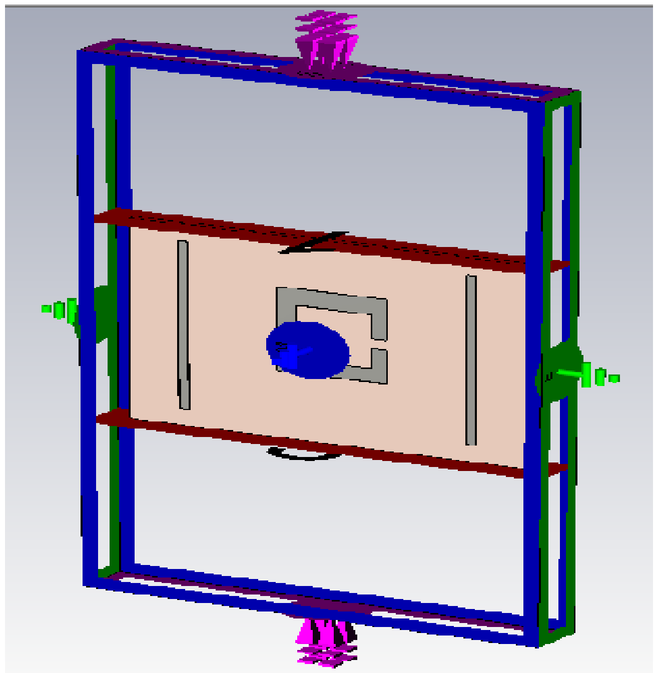

FIG. 11 PROPOSED METAMATERIAL STRUCTURE BETWEEN THE TWO WAVEGUIDE PORTS.

In NRW approach, proposed design of transceiver having metamaterial structure was placed between two waveguide ports on both sides of transceiver on Y-axis to calculate S11 and S21 parameters. X and Z planes are defined as the perfect electric and magnetic boundary respectively. Following that, the wave was excited toward the port 2 from port 1 or up to down.

Later on, after the simulation in CST-MWS software the S11 and S21 parameters were exported to MS Excel software for further calculation. In MS Excel equation no. (6) & (7) were used to prove structure that it is metamaterial. The result of NRW approach shows negative permeability and permittivity in figure 12 & 13 respectively.

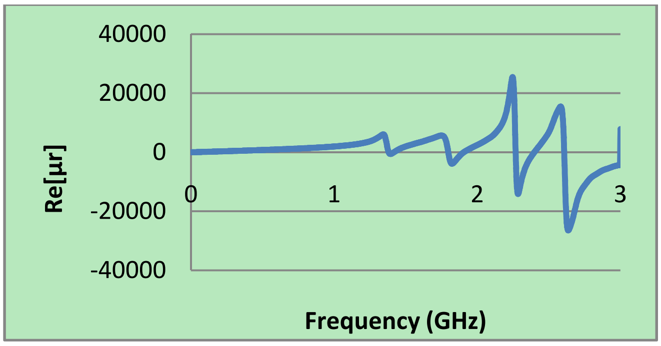

FIG.12 PERMEABILITY VERSUS FREQUENCY GRAPH OBTAINED FROM EXCEL SOFTWARE.

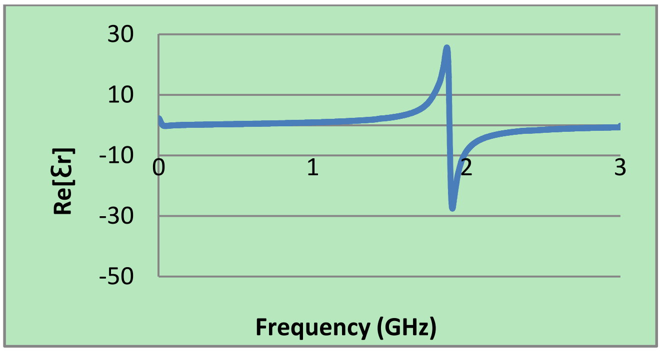

FIG. 13 PERMITTIVITY VERSUS FREQUENCY GRAPH OBTAINED FROM EXCEL SOFTWARE.

Generated excel sheet for permittivity and permeability has number of data but here some data has been shown which lies within operating frequency range.

Simulation Results & Discussion

By putting the emphasis on innovative rectangular microstrip split ring resonator metamaterial structure of RMT, Figure 3 shows the configuration of the proposed rectangular microstrip transceiver covered with innovative metamaterial structure at a height of 3.276 mm from the ground plane and size of 29.7794 mm X 38.3934 mm, thickness of the substrate 1.6 mm; above which metamaterial structure is placed with the separation *h* = 3.276 mm from the ground plane. Through the simulation of the transceiver on CST-MWS, the bandwidth has significantly improved by 487%, the return loss has reduce by 117%, directivity and efficiency have improved by 96% and 22 %, respectively as shown in figure 4,5,6 & 7. Smith Charts in figure 7 & 8 of the transceiver show the impedance at simulated frequency. By means of the NRW method in MS-Excel Software, the negative permeability & negative permittivity have been proved. The tables for permeability & permittivity generated by the MS-Excel Software are too large between the simulated frequency ranges 1-3 GHz. Therefore, TABLE 2 & TABLE 3 show the negative values of permeability & permittivity of the limited samples only in the frequency range 2.2950001-2.3100002 GHz. The Figure 12 & 13 shows the negative values of permeability & permittivity of the proposed innovative metamaterial structure.

TABLE 2 SAMPLED VALUES OF PERMEABILITY AT 2.301 GHZ CALCULATED ON MS EXCEL SOFTWARE.

Frequency [GHz]	Permeability [μr]	Re[μr]
2.2950001	-12611.6827797665-13920.400386382i	-12611.7
2.2979999	-11925.8114091231-12489.7580618615i	-11925.8
2.3009999	-11230.8789804144-11293.1166113969i	-11230.9
2.3039999	-10549.9218272135-10286.6048953935i	-10549.9
2.3069997	-9894.76908055908-9436.8003123281i	-9894.77
2.3100002	-9272.08237188567-8713.90680299498i	-9272.08

TABLE 3 SAMPLED VALUES OF PERMITTIVITY AT 2.301 GHz CALCULATED ON MS EXCEL SOFTWARE.

Frequency [GHz]	Permittivity [□r]	Re[□r]
2.2950001	-2.29168237746883-0.182955078488774i	-2.29168
2.2979999	-2.27231992459286-0.182432768926599i	-2.27232
2.3009999	-2.25317969065151-0.182026054604298i	-2.25318
2.3039999	-2.23425359365939-0.181738984291652i	-2.23425
2.3069997	-2.21555521340044-0.181575582709736i	-2.21556
2.3100002	-2.19707633835789-0.181540387664733i	-2.19708

Conclusion

A new design methodology has been presented in this paper to create a highly improved rectangular microstrip transceiver by adding a single layer that contains a combination of rectangular split ring resonator like structure. That has been proved as a metamaterial. Because the construction is simple, improved transceiver can be produced with little effort at low cost. Based on the simulation results, it is observed that the impedance bandwidth of the RMT is improved by 487%, return loss is reduced by 117%, directivity and efficiency have improved by 96% and 22%, respectively via the incorporation of the proposed metamaterial structure. This is remarkable improvement in S-band (2-4 GHz), when compared to the results of RMT alone. It is clearly observed that the return loss, bandwidth and directivity have improved significantly by means of incorporating the proposed

metamaterial structure at 3.276 mm layer from the ground plane of the rectangular microstrip transceiver. Along with these improvements, this structure satisfies Double Negative property within the simulated frequency range.

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